Chapter 4
Calculations and Presentations

4-1. Analysis Methods

a. Selection of suitable methods of analysis. The methods of analysis (computer program, charts, hand calculations) should be selected according to the complexity of the site or job and the data available to define the site conditions.

(1) Use of a reliable and verified slope stability analysis computer program is recommended for performing slope stability analyses where conditions are complex, where significant amounts of data are available, and where possible consequences of failure are significant. Computer programs provide a means for efficient and rapid detailed analysis of a wide variety of slope geometry and load conditions.

(2) Slope stability charts are relatively simple to use and are available for analysis of a variety of short-term and long-term conditions. Appendix E contains several different types of slope stability charts and guidance for their use.

(3) Spreadsheet analyses can be used to verify results of detailed computer analyses.

(4) Graphical (force polygon) analyses can also be used to verify results of computer analyses.

b. Verification of analysis method. Verification of the results of stability analyses by independent means is essential. Analyses should be performed using more than one method, or more than one computer program, in a manner that involves independent processing of the required information and data insofar as practical, to verify as many aspects of the analysis as possible. Many slope stability analyses are performed using computer programs. Selection and verification of suitable software for slope stability analysis is of prime importance. It is essential that the software used for analysis be tested and verified, and the verification process should be described in the applicable design and analysis memoranda (geotechnical report). Thorough verification of computer programs can be achieved by analyzing benchmark slope stability problems. Benchmark problems are discussed by Edris, Munger, and Brown (1992) and Edris and Wright (1992).

4-2. Verification of Computer Analyses and Results

a. General. All reports, except reconnaissance phase reports, that deal with critical embankments or slopes should include verification of the results of computer analyses. The verification should be commensurate with the level of risk associated with the structure and should include one or more of the following methods of analysis using:

(1) Graphical (force polygon) method.

(2) Spreadsheet calculations.

(3) Another slope stability computer program.

(4) Slope stability charts.

The historical U.S. Army Corps of Engineers' approach to verification of any computer analysis was to perform hand calculations (force polygon solution) of at least a simplified version of the problem. It was acceptable to simplify the problem by using fewer slices, by averaging unit weights of soil layers, and by simplifying the piezometric conditions. While verification of stability analysis results is still required, it is no longer required that results be verified using graphical hand calculations. Stability analysis results can be verified using any of the methods listed above. Examples of verifications of analyses performed using Spencer's Method, the Simplified Bishop Method, and the Modified Swedish Method are shown in Figures 4-1, 4-2, 4-3, and 4-4.

b. Verification using a second computer program. For difficult and complex problems, a practical method of verifying or confirming computer results may be by the use of a second computer program. It is desirable that the verification analyses be performed by different personnel, to minimize the likelihood of repeating data entry errors.

c. Software versions. Under most Microsoft Windows™ operating systems, the file properties, including version, size, date of creation, and date of modification can be reviewed to ensure that the correct version of the computer program is being used. Also, the size of the computer program file on disk can be compared with the size of the original file to ensure that the software has not been modified since it was verified. In addition, printed output may show version information and modification dates. These types of information can be useful to establish that the version of the software being used is the correct and most recent version available.

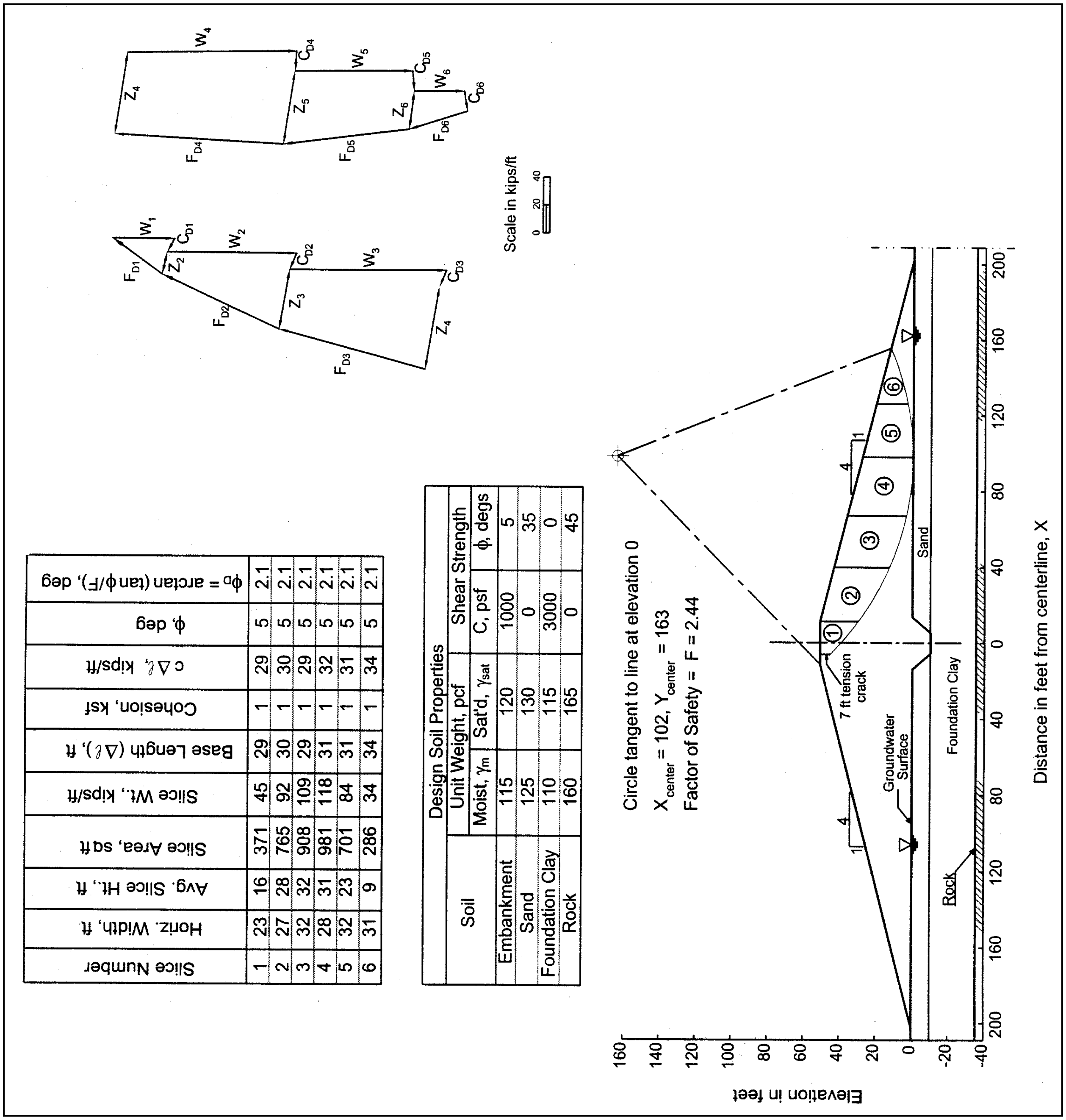
d. Essential requirements for appropriate use of computer programs. A thorough knowledge of the capabilities of the software and knowledge of the theory of limit equilibrium slope stability analysis methods will allow the user to determine if the software available is appropriate for the problem being analyzed.

(1) To verify that data are input correctly, a cross section of the problem being analyzed should be drawn to scale and include all the required data. The input data should be checked against the drawing to ensure the data in the input file are correct. Examining graphical displays generated from input data is an effective method of checking data input.

(2) The computed output should be checked to ensure that results are reasonable and consistent. Important items to check include the weights of slices, shear strength properties, and pore water pressures at the bottoms of slices. The user should be able to determine if the critical slip surface is going through the material it should. For automatic searches, the output should designate the most critical slip surface, as well as what other slip surfaces were analyzed during the search. Checking this information thoroughly will allow the user to determine that the problem being analyzed was properly entered into the computer and the software is correctly analyzing the problem.

e. Automatic search verification. Automatic searches can be performed for circular or noncircular slip surfaces. The automatic search procedures used in computer programs are designed to aid the user in locating the most critical slip surface corresponding to a minimum factor of safety. However, considerable judgment must be exercised to ensure that the most critical slip surface has actually been located. More than one local minimum may exist, and the user should use multiple searches to ensure that the global minimum factor of safety has been found.

(1) Searches with circular slip surfaces. Various methods can used to locate the most critical circular slip surfaces in slopes. Regardless of the method used, the user should be aware of the assumptions and limitations in the search method.



Slice Number	Horiz. Width, ft	Avg. Slice Ht., ft	Slice Area, sq ft	Slice Wt., kips/ft	Base Length ($\Delta\ell$), ft	Cohesion, ksf	$c\Delta\ell$, kips/ft	ϕ, deg	ϕ_D = arctan ($\tan\phi$/F), deg
1	23	16	371	45	29	1	29	5	2.1
2	27	28	765	92	30	1	30	5	2.1
3	32	32	908	109	29	1	29	5	2.1
4	28	31	981	118	31	1	32	5	2.1
5	32	23	701	84	31	1	31	5	2.1
6	31	9	286	34	34	1	34	5	2.1

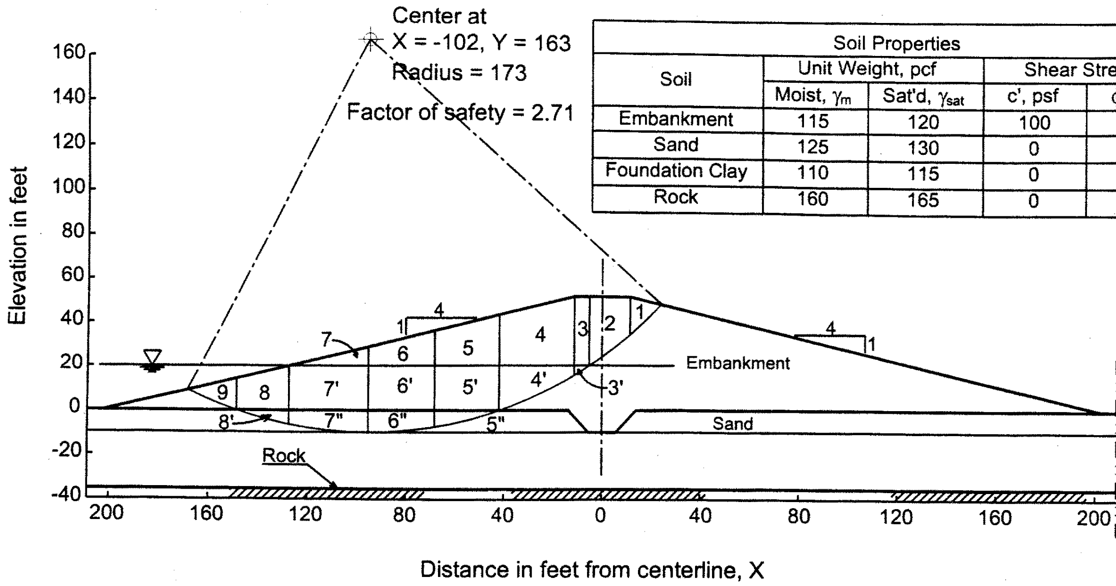
Design Soil Properties

Soil	Unit Weight, pcf		Shear Strength	
	Moist, γ_m	Sat'd, γ_{sat}	C, psf	ϕ, degs
Embankment	115	120	1000	5
Sand	125	130	0	35
Foundation Clay	110	115	3000	0
Rock	160	165	0	45

Figure 4-1. Hand verification using force equilibrium procedure to check stability computations performed via Spencer's Method – end-of-construction conditions

(a) During an automatic search, the program should not permit the search to jump from one face of the slope to another. If the initial trial slip surface is for the left face of the slope, slip surfaces on the right face of the slope should be rejected.

(b) In some cases, a slope may have several locally critical circles. The center of each such locally critical circle is surrounded by centers of circles that have higher values for the factor of safety. In such cases, when a search is performed, only one of the locally critical circles will be searched out, and the circle found may not be the one with the overall lowest factor of safety. To locate the overall critical



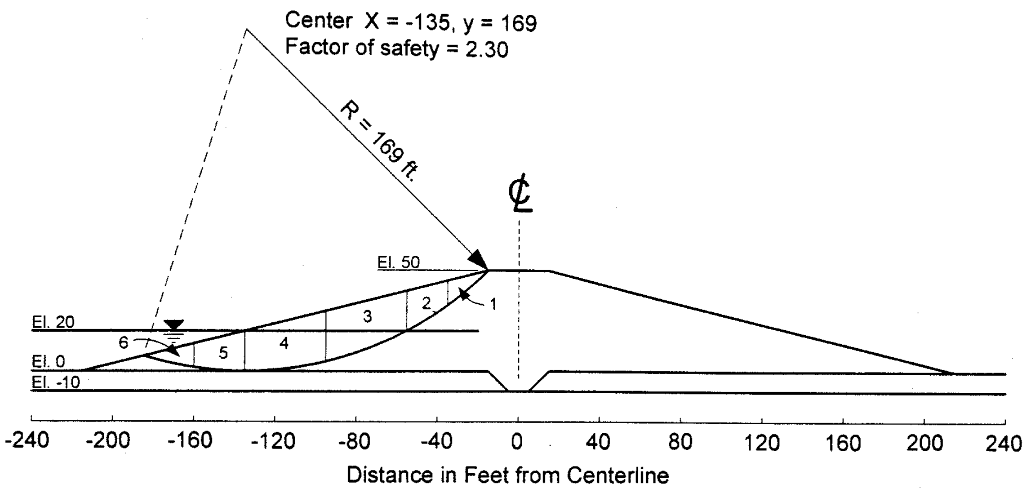
Soil	Unit Weight, pcf		Shear Strength	
	Moist, γ_m	Sat'd, γ_{sat}	c', psf	ϕ', degs
Embankment	115	120	100	25
Sand	125	130	0	35
Foundation Clay	110	115	0	28
Rock	160	165	0	45

Soil Properties

Slice Number	Horizontal Width (b), ft	Average Slice Height, ft	Slice Area, sq. ft	Total Unit Weight (γ), pcf	Partial Weights, kips	Total Weight (W), kips	Base Inclination (α), deg	W sin(α)	Ht. of Surface Water, ft	Avg. Surface Press., ksf	Base Inclination (α), deg	Surface Load (P), kips/ft	Horiz Moment Arm (d_h), ft	Vert Moment Arm (d_v), ft	Moment (MP), kip-ft	Piezometric Height, ft	Pore Water Pressure (u), ksf	Cohesion (c), ksf	Friction Angle (ϕ), deg	c'b + (W + Pcosβ - ub)tanϕ'	m_α(F=2.71)	[c'b+(W + Pcos β - ub)tan ϕ')] m_α
1	11	7	83	115	10	10	45	7	-	-	-	-	-	-	-	0	0.00	0.1	25	6	0.83	7
2	20	22	436	115	50	50	38	31	-	-	-	-	-	-	-	0	0.00	0.1	25	25	0.89	28
3 3'	10	30 3	311 34	115 120	36 4	40	32	21	-	-	-	-	-	-	-	3	0.20	0.1	25	19	0.94	20
4 4'	29	26 13	766 385	115 120	88 46	134	25	57	-	-	-	-	-	-	-	13	0.83	0.1	25	54	0.98	55
5 5' 5''	29	19 20 4	554 579 109	115 120 130	64 70 14	147	15	37	-	-	-	-	-	-	-	24	1.48	0	35	73	1.03	71
6 6' 6''	29	12 20 9	344 580 254	115 120 130	40 70 33	142	5	12	-	-	-	-	-	-	-	29	1.80	0	35	63	1.02	62
7 7' 7''	33	4 20 8	136 660 278	115 120 130	16 79 36	131	-6	-13	-	-	-	-	-	-	-	28	1.77	0	35	51	0.97	52
8 8'	25	17 3	421 85	120 130	51 11	62	-15	-16	3	0.19	14	5	45	146	399	23	1.46	0	35	21	0.90	23
9	20	7	139	120	17	17	-23	-7	9	0.55	14	11	68	152	1176	16	0.98	0.1	25	6	0.85	7
								129							1574							326

$$F = \frac{326}{129 - \frac{1574}{173}} = 2.71$$

Figure 4-2. Verification of computations using a spreadsheet for the Simplified Bishop Method – upstream slope, low pool



Material Properties

Soil	Cohesion	ϕ	Unit Weight
Embankment	200 psf	25 deg	115 pcf
Foundation Sand	0	35 deg	130 pcf
Foundation Clay	0	27 deg	115 pcf

Slice	Horizontal Width (b), ft	Avg. Slice Ht., ft	Slice Area, sq ft	Slice Weight (W), kips	Piezometric Ht.-Center, ft	Ht. of Surface Water, ft	Press. at top of Slice, ksf	Slope at Top of Slice, deg	Length of Top of Slice, deg	Surface Load (P), kips	Slice Base Length ($\Delta\ell$), ft	Pore Water Pressure (u), ksf	$U_b = u\Delta\ell$, kips	$c'\Delta\ell$, kips	$C_D = c'\Delta\ell/F$, kips	$\phi_D = \arctan(\tan(\phi')/F)$, deg
1	20	6	122	14	0	0	0	14	21	0	26	0.00	0	5.3	2.3	11.5
2	20	16	326	37	0	0	0	14	21	0	24	0.00	0	4.8	2.1	11.5
3	40	23	897	103	8	0	0	14	41	0	40	0.47	20	8.5	3.7	11.5
4	40	23	904	104	18	0	0	14	41	0	43	1.10	44	8.1	3.5	11.5
5	25	16	399	46	19	3	0.20	14	26	5	24	1.19	30	5.0	2.2	11.5
6	25	6	148	17	15	9	0.58	14	26	15	26	0.96	24	5.1	2.2	11.5

Figure 4-3. Hand verification of computations using the Modified Swedish Method – upstream slope, low pool (Part 1 of 2, computed forces)

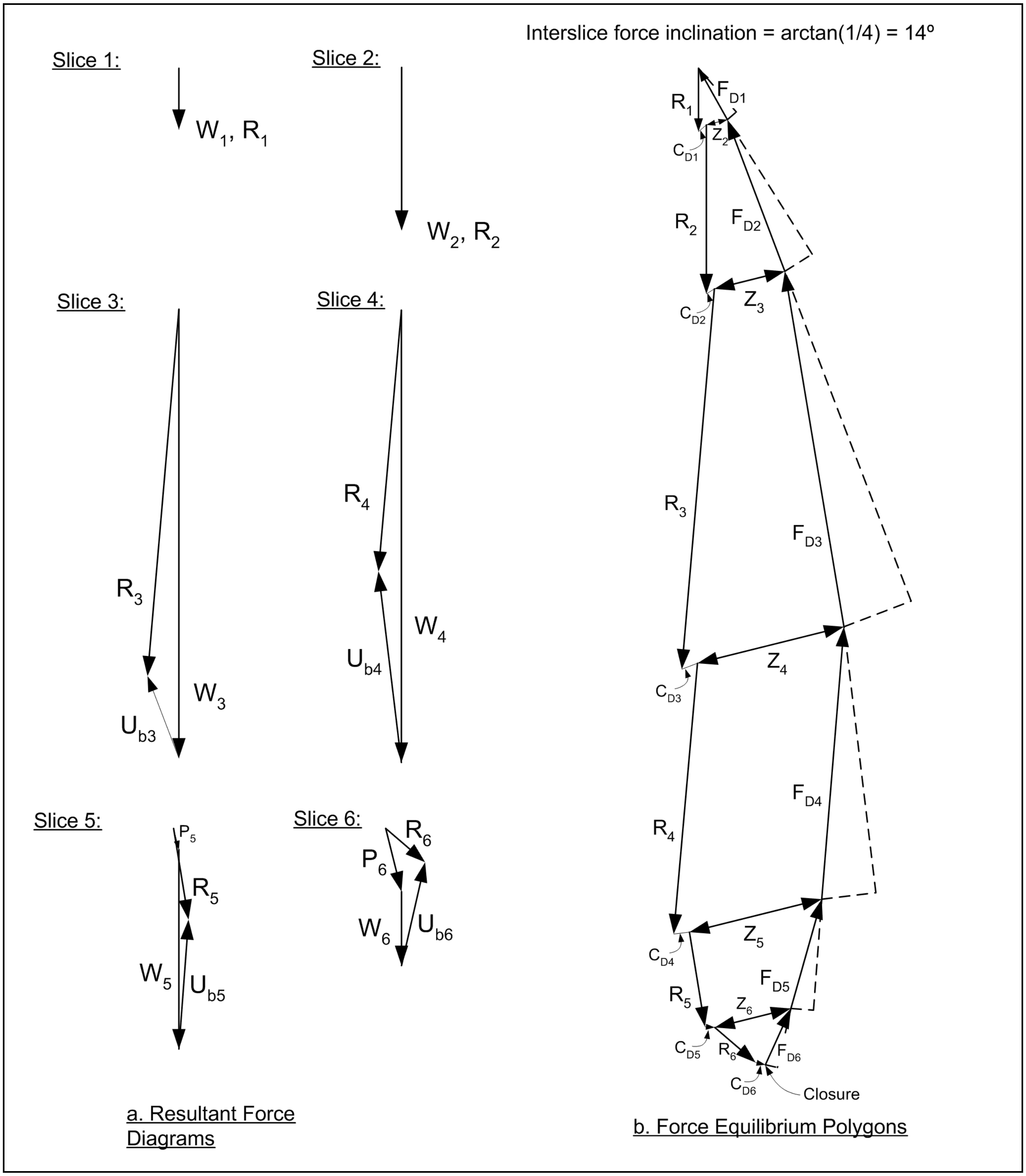


Figure 4-4. Hand verification of computations using the Modified Swedish Method (Part 2 of 2 – force polygons)

circle, several automatic searches should be performed using different starting points for the centers of the circles. The values of the factor of safety for each of the critical circles located by these independently started searches should then be compared by the user to determine the overall minimum factor of safety, and the location of the corresponding critical circle. This requires the user to perform several independently started searches for a given problem.

(c) An alternative approach is to perform analyses for a suite of circles with selected center points, and to vary the radii or depths of the circles for each center point. The computed factors of safety can be examined to determine the location of the most critical circle and the corresponding minimum factor of safety.

(2) Searches with noncircular slip surfaces. As with circular slip surfaces, various methods are used to search for critical noncircular slip surfaces. In all of these methods, the initial position of the slip surface is specified by the user and should correspond to the estimated position of the critical slip surface.

(a) In most methods of limit equilibrium slope stability analysis, the equilibrium equations used to compute the factor of safety may yield unrealistic values for the stresses near the toes of slip surfaces that are inclined upward at angles much steeper than those that would be logical based on considerations of passive earth pressure. Trial slip surfaces may become excessively steep in an automatic search unless some restriction is placed on their orientation.

(b) Because procedures for searching for critical noncircular slip surfaces have been developed more recently than those for circles, there is less experience with them. Thus, extra care and several trials may be required to select optimum values for the parameters that control the automatic search. The search parameters should be selected such that the search will result in an acceptably refined location for the most critical slip surface. The search parameters should be selected so that the final increments of distance used to shift the noncircular slip surface are no more than 10 to 25 percent of the thickness of the thinnest stratum through which the shear surface may pass.

4-3. Presentation of the Analysis and Results

a. Basic requirements. The description of the slope stability analysis should be concise, accurate, and self-supporting. The results and conclusions should be described clearly and should be supported by data.

b. Contents. It is recommended that the documentation of the stability analysis should include the items listed below. Some of the background information may be included by reference to other design documents. Essential content includes:

(1) Introduction.

(a) Scope. A brief description of the objectives of the analysis.

(b) Description of the project and any major issues or concerns that influence the analysis.

(c) References to engineering manuals, analysis procedures, and design guidance used in the analysis.

(2) Regional geology. Refer to the appropriate design memorandum, if published. If there is no previously published document on the regional geology, include a description of the regional geology to the extent that the regional geology is pertinent to the stability analysis.

(3) Site geology and subsurface explorations. Present detailed site geology including past and current exploration, drilling, and sampling activities. Present geologic maps and cross sections, in sufficient number and detail, to show clearly those features of the site that influence slope stability.

(4) Instrumentation and summary of data. Present and discuss any available instrumentation data for the site. Items of interest are piezometric data, subsurface movements observed with inclinometers, and surface movements.

(5) Field and laboratory test results.

(a) Show the location of samples on logs, plans, and cross sections.

(b) Present a summary of each laboratory test for each material, using approved forms as presented in EM 1110-2-1906, for laboratory soils testing.

(c) Show laboratory test reports for all materials. Examples are shown in Figures 4-5, 4-6, 4-7, 4-8, 4-9, and 4-10.

(d) Discuss any problems with sampling or testing of materials.

(e) Discuss the use of unique or special sampling or testing procedures.

(6) Design shear strengths. Present the design shear strength envelopes, accompanied by the shear strength envelopes developed from the individual test data for each material in the embankment, foundation, or slope, for each load condition analyzed. An example is shown in Figure 4-11.

(7) Material properties. Present the material properties for all the materials in the stability cross section, as shown in Figure 4-12. Explain how the assigned soil property values were obtained. In the case of an embankment, specify the location of the borrow area from which the embankment material is to be obtained. Discuss any factors regarding the borrow sites that would impact the material properties, especially the natural moisture content, and expected variations in the materials in the borrow area.

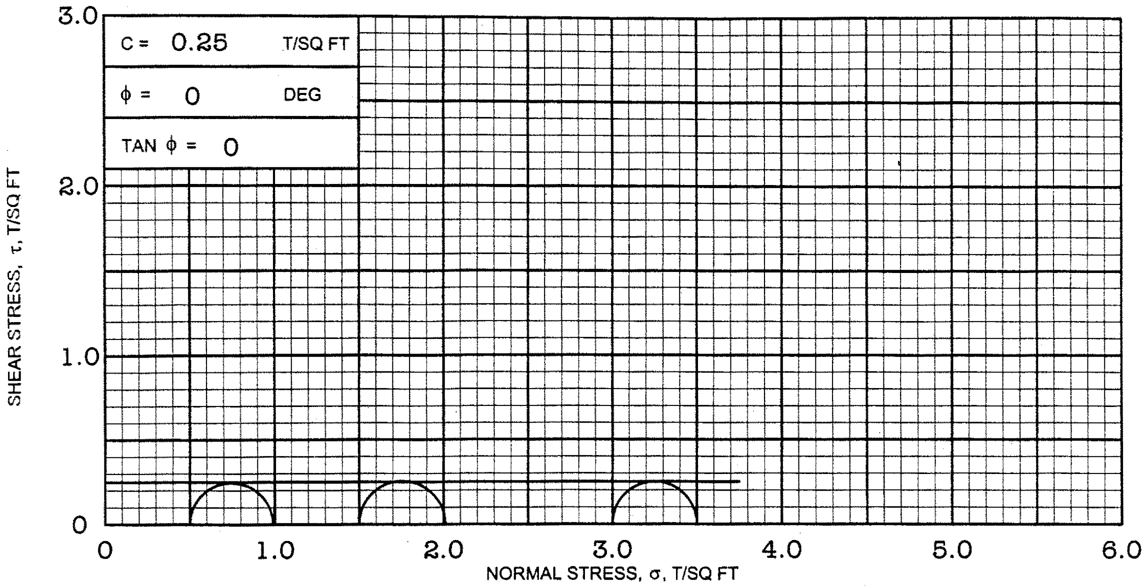
(8) Groundwater and seepage conditions. Present the pore water pressure information used in the stability analysis. Show the piezometric line(s) or discrete pore pressure points in the cross section used in the analysis, as shown in Figure 4-12. If the piezometric data are derived from a seepage analysis, include a summary of the seepage analysis in the report. Include all information used to determine the piezometric data, such as water surface levels in piezometers, artesian conditions at the site, excess pore water pressures measured, reservoir and river levels, and drawdown levels for rapid drawdown analysis.

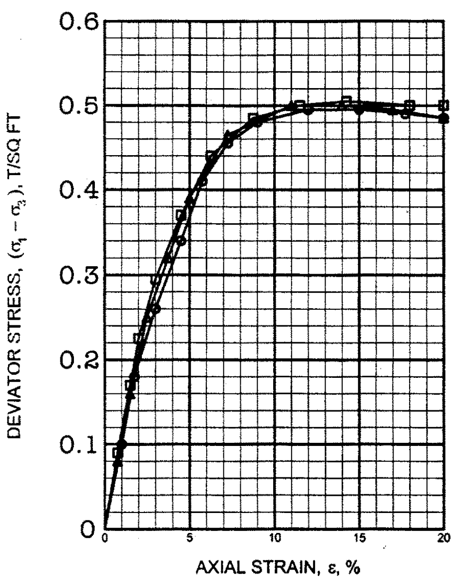
(9) Stability analyses.

(a) State the method used to perform the slope stability analysis, e.g., Spencer's Method in a given computer program, Modified Swedish Method using hand calculations with the graphical (force polygon) method, or slope stability charts. Provide the required computer software verification information described in Section 4-1.

(b) For each load condition, present a tabulation of material property values, show the cross section analyzed on one or more figures, and show the locations and the factors of safety for the critical and other significant slip surfaces, as shown in Figure 4-12. For circular slip surfaces, show the center point, including the coordinates, and the value of radius.

(c) For the critical slip surface for each load condition, describe how the factor of safety results were verified and include details of the verification procedure, as discussed previously.





				○ 1	□ 2	△ 3	
SPECIMEN NO.				○ 1	□ 2	△ 3	
INITIAL	WATER CONTENT, %		w_o	28.9	29.3	31.6	
	DRY DENSITY LBS CU FT		γ_{d_o}	93.0	89.8	88.3	
	SATURATION, %		S_o	96.1	90.2	93.8	
	VOID RATIO		e_o	0.812	0.877	0.909	
BEFORE SHEAR	WATER CONTENT, %		w_c				
	DRY DENSITY LBS CU FT		γ_{d_c}				
	SATURATION, %		S_c				
	VOID RATIO		e_c				
	FINAL BACK PRESSURE T/SQ FT		u_b				
MINOR PRINCIPAL STRESS, T/SQ FT			σ_3	0.5	1.5	3.0	
MAXIMUM DEVIATOR STRESS, T/SQ FT		$(\sigma_1 - \sigma_3)_{max}$		0.49	0.51	0.50	
TIME TO $(\sigma_1 - \sigma_3)_{max}$, MIN			t_f	30	30	30	
ULTIMATE DEVIATOR STRESS, T/SQ FT		$(\sigma_1 - \sigma_3)_{ult}$		0.485	0.485	0.500	
INITIAL DIAMETER, IN.			D_o	1.40	1.40	1.40	
INITIAL HEIGHT, IN.			H_o	3.00	3.00	3.00	

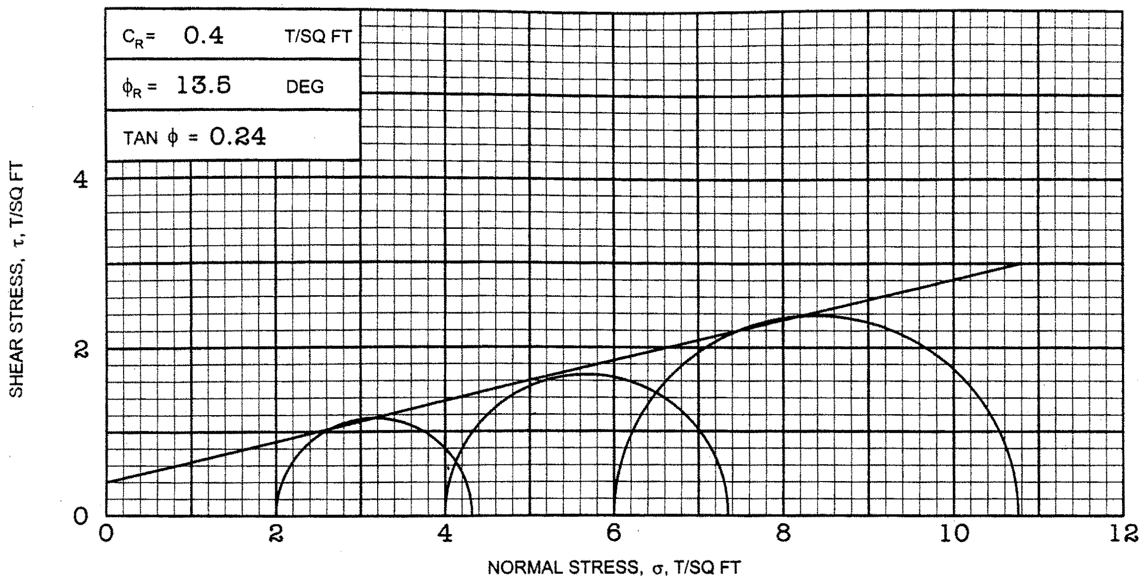
CONTROLLED - STRAIN TEST

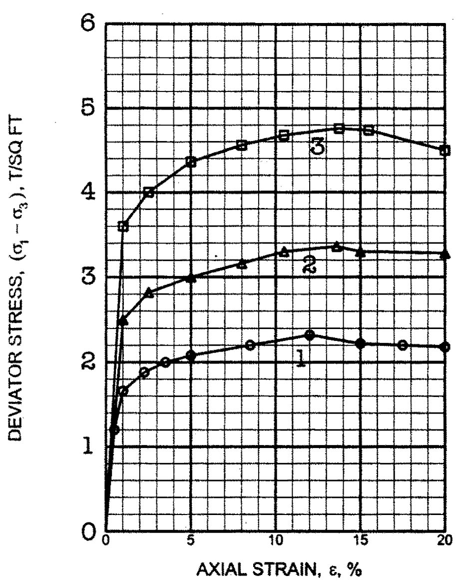
DESCRIPTION OF SPECIMENS SILTY CLAY (CL), GRAY

LL 28	PL 20	PI 8	Gs 2.70	TYPE OF SPECIMEN UNDISTURBED	TYPE OF TEST Q

REMARKS	PROJECT YATESVILLE DAM	
	BORING NO. UD-84-5	SAMPLE NO. 3
	DEPTH/ELEV 16.0/17.5	
	LABORATORY ORD	DATE 21 AUG 84
	TRIAXIAL COMPRESSION TEST REPORT	

Figure 4-5. Triaxial compression test report for Q (unconsolidated-undrained) tests





SPECIMEN NO.			1	2	3	
INITIAL	WATER CONTENT, %	w_o	27.3	28.3	28.0	
	DRY DENSITY LBS CU FT	γ_{d_o}	98.2	94.6	95.9	
	SATURATION, %	S_o	100	97.8	99.7	
	VOID RATIO	e_o	0.717	0.782	0.758	
BEFORE SHEAR	WATER CONTENT, %	w_c	25.4	24.6	24.2	
	DRY DENSITY LBS CU FT	γ_{d_c}	103.9	103.4	105.0	
	SATURATION, %	S_c	100	100	100	
	VOID RATIO	e_c	0.622	0.630	0.605	
	FINAL BACK PRESSURE T/SQ FT	u_b	5.76	5.76	5.76	
MINOR PRINCIPAL STRESS, T/SQ FT		σ_3	2.0	4.0	6.0	
MAXIMUM DEVIATOR STRESS, T/SQ FT		$(\sigma_1 - \sigma_3)_{max}$	2.32	3.35	4.76	
TIME TO $(\sigma_1 - \sigma_3)_{max}$, MIN		t_f	793	913	920	
ULTIMATE DEVIATOR STRESS, T/SQ FT		$(\sigma_1 - \sigma_3)_{ult}$	2.18	3.28	4.50	
INITIAL DIAMETER, IN.		D_o	1.35	1.36	1.35	
INITIAL HEIGHT, IN.		H_o	3.00	3.00	3.00	

CONTROLLED - STRAIN TEST

DESCRIPTION OF SPECIMENS SILTY CLAY (CL), GRAY

LL 27	PL 17	PI 10	Gs 2.70	TYPE OF SPECIMEN UNDISTURBED	TYPE OF TEST R-BAR

REMARKS

PROJECT YATESVILLE DAM

BORING NO. UD-84-3 | SAMPLE NO. 1

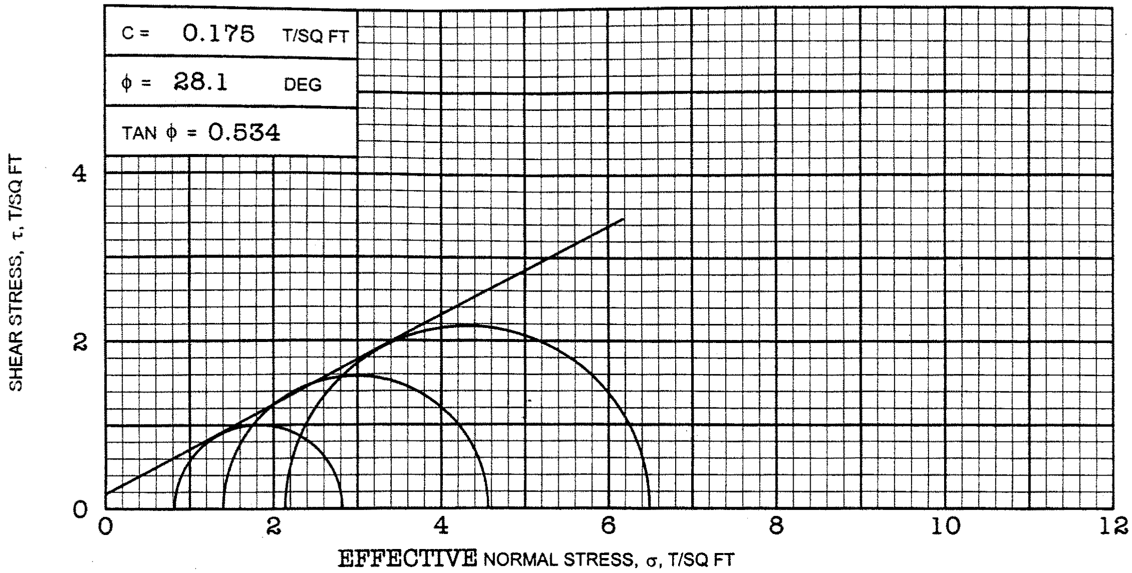
DEPTH/ELEV 18.0/19.8

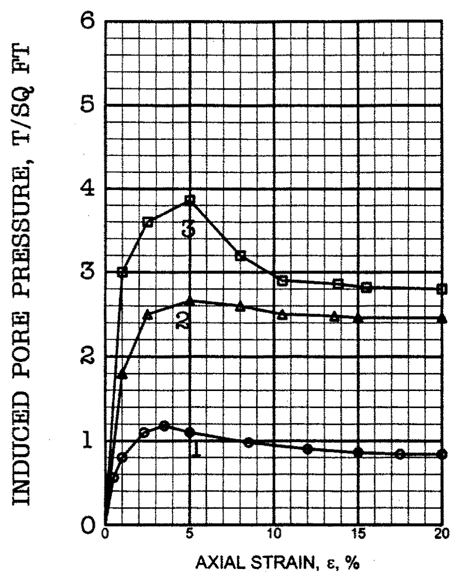
LABORATORY USAEWES | DATE 31 JULY 1984

SHEET 1 OF 3

TRIAXIAL COMPRESSION TEST REPORT

Figure 4-6. Triaxial compression test report for R-bar (consolidated-undrained) tests – total stress envelope





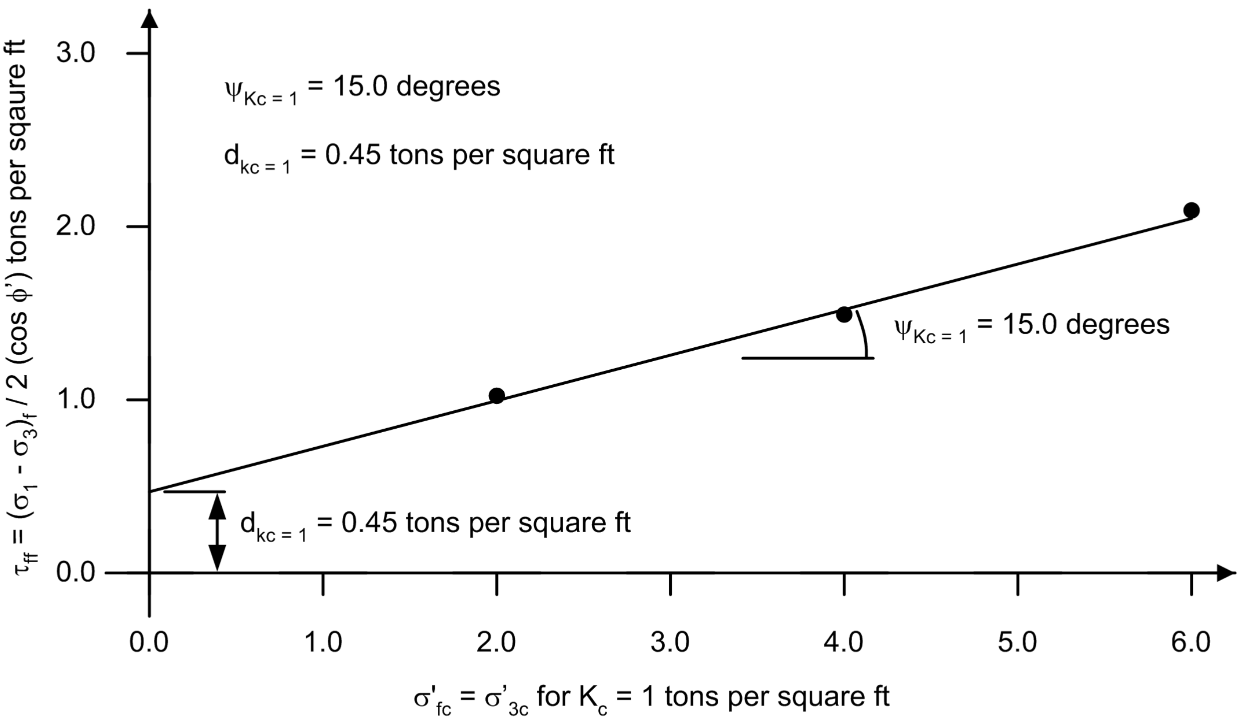
SPECIMEN NO.			1	2	3
INITIAL	WATER CONTENT, %	w_o	27.3	28.3	28.0
	DRY DENSITY LBS CU FT	γ_{d_o}	98.2	94.6	95.9
	SATURATION, %	S_o	100	97.8	99.7
	VOID RATIO	e_o	0.717	0.782	0.758
BEFORE SHEAR	WATER CONTENT, %	w_c	25.4	24.6	24.2
	DRY DENSITY LBS CU FT	γ_{d_c}	103.9	103.4	105.0
	SATURATION, %	S_c	100	100	100
	VOID RATIO	e_c	0.622	0.630	0.605
	FINAL BACK PRESSURE T/SQ FT	u_b	5.76	5.76	5.76
MINOR PRINCIPAL STRESS, T/SQ FT		σ_3	0.82	1.40	2.14
MAXIMUM DEVIATOR STRESS, T/SQ FT		$(\sigma_1 - \sigma_3)_{max}$	2.00	3.16	4.35
TIME TO $(\sigma_1 - \sigma_3)_{max}$, MIN		t_f	793	913	920
ULTIMATE DEVIATOR STRESS, T/SQ FT		$(\sigma_1 - \sigma_3)_{ult}$	2.18	3.28	4.50
INITIAL DIAMETER, IN.		D_o	1.35	1.36	1.35
INITIAL HEIGHT, IN.		H_o	3.00	3.00	3.00

CONTROLLED - STRAIN TEST

DESCRIPTION OF SPECIMENS SILTY CLAY (CL), GRAY

LL 27	PL 17	PI 10	Gs 2.70	TYPE OF SPECIMEN UNDISTURBED	TYPE OF TEST R-BAR
REMARKS				PROJECT YATESVILLE DAM	
				BORING NO. UD-84-3	SAMPLE NO. 1
				DEPTH/ELEV 18.0/19.8	
				LABORATORY USAEWES	DATE 31 JULY 1984
SHEET 2 OF 3				TRIAXIAL COMPRESSION TEST REPORT	

Figure 4-7. Triaxial compression test report for R-bar (consolidated-undrained) tests – effective stress envelope

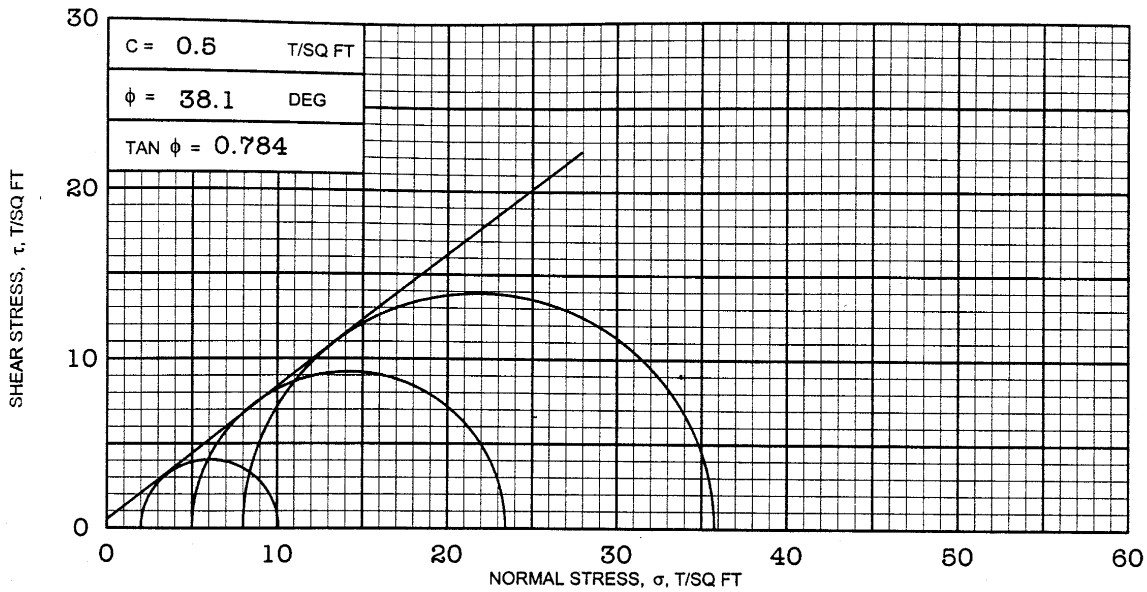


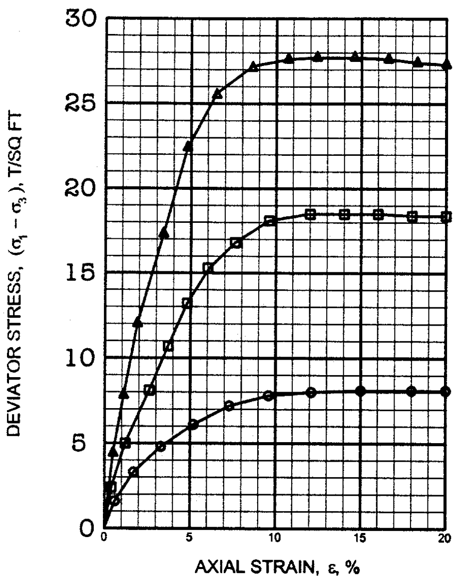
Test	$\sigma'_{fc} = \sigma'_{3c}$ (tsf)	$(\sigma_1 - \sigma_3)$ (tsf)	τ_{ff} (tsf)
1	2.00	2.32	1.02
2	4.00	3.35	1.48
3	6.00	4.76	2.10

Note: ϕ' = 28.1 degrees, $\cos \phi'$ = 0.88

Sheet 3 of 3

Figure 4-8. Variation of τ_{ff} with σ'_{fc} for R-bar test with isotropic consolidation





SPECIMEN NO.			○ 1	□ 2	△ 3	
INITIAL	WATER CONTENT, %	w_o	4.9	4.4	4.5	
	DRY DENSITY LBS CU FT	γ_{d_o}	120.1	120.7	120.6	
	SATURATION, %	S_o	34.9	31.6	32.3	
	VOID RATIO	e_o	0.372	0.365	0.366	
BEFORE SHEAR	WATER CONTENT, %	w_c	12.9	12.4	11.1	
	DRY DENSITY LBS CU FT	γ_{d_c}	122.8	124.1	127.5	
	SATURATION, %	S_c	100	100	100	
	VOID RATIO	e_c	0.341	0.327	0.292	
	FINAL BACK PRESSURE T/SQ FT	u_b	4.00	4.00	4.00	
MINOR PRINCIPAL STRESS, T/SQ FT		σ_3	2.00	5.00	8.00	
MAXIMUM DEVIATOR STRESS, T/SQ FT		$(\sigma_1 - \sigma_3)_{max}$	8.09	18.44	27.76	
TIME TO $(\sigma_1 - \sigma_3)_{max}$, MIN		t_f	150	110	130	
ULTIMATE DEVIATOR STRESS, T/SQ FT		$(\sigma_1 - \sigma_3)_{ult}$	8.09	18.41	27.43	
INITIAL DIAMETER, IN.		D_o	14.88	14.88	14.88	
INITIAL HEIGHT, IN.		H_o	32.00	32.00	32.00	

CONTROLLED - STRAIN (0.1%/min) TEST

DESCRIPTION OF SPECIMENS Gray & tan poorly graded crusher run sandstone (GP)

LL 20	PL 18	PI 2	Gs 2.64	TYPE OF SPECIMEN REMOLDED	TYPE OF TEST S

REMARKS

Specimens requested to be remolded at field moisture content to a dry density of 120 pcf

PROJECT YATESVILLE DAM

PROPOSED ROCK EXCAVATION - SANDSTONE

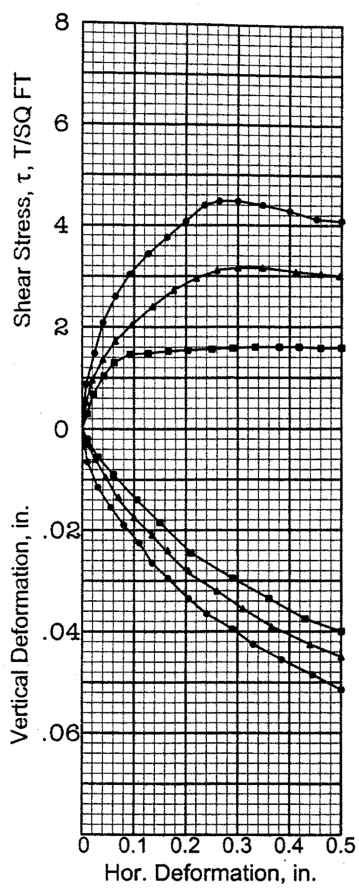
BORING NO. C-82, C-84, C-85 SAMPLE NO.

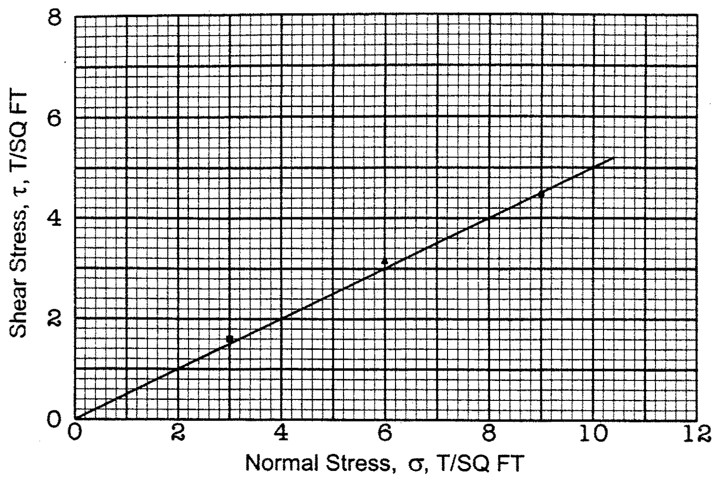
DEPTH/ELEV 808.5 TO 758.8

LABORATORY SADEL DATE 26 DEC 73

TRIAXIAL COMPRESSION TEST REPORT

Figure 4-9. Triaxial compression test report for S (drained) tests – effective stress envelope





Shear Strength Parameters

ϕ' = 27.0 deg

tan ϕ' = 0.510

c' = 0.0 T/sq ft

☐ Controlled stress

☒ Controlled strain

Test No.						
Initial	Water content	w_o	24.4%	24.4%	24.4%	
	Void ratio	e_o	0.769	0.709	0.779	
	Saturation	S_o	87%	95%	86%	
	Dry density lb/cu ft	γ_d	97.2	100.4	96.5	
Void ratio after consolidation		e_c	0.694	0.615	0.610	
Time for 50 percent consolidation, min		t_{50}	16	24	23	
Final	Water content	w_f	23.3%	26.1%	26.4	
	Void ratio	e_f	0.555	0.464	0.424	
	Saturation	S_f	100	100	100	
Normal stress T/sq ft		σ	3.0	6.0	9.0	
Maximum shear stress, T/sq ft		τ_{max}	1.60	3.16	4.47	
Actual time to failure, min		t_f	500	600	600	
Rate of displ., in/min			0.0003	0.0003	0.0003	
Ultimate shear stress, T/sq ft		τ_{ult}	1.58	3.00	4.08	

Type of specimen Undisturbed			3.25 in. square	0.50 in. thick
Classification Brown and Gray Lean CLAY (CL)				
LL 34.1	PL 20.9	PI 13.2		G_s 2.75
Remarks		Project Yatesville Dam		
		Area		
		Boring No. UD-1A	Sample No. 4	
		Depth/Elev 579.5-577.0	Date DEC 1973	
		DIRECT SHEAR TEST REPORT		

Figure 4-10. Direct shear test report – effective stress envelope

Boring	Sample	Depth - ft	Specimen	Moist density	Saturated density	C' tsf	ϕ' degrees
UD-2	1	42.0 - 44.0	1	126.0	129.9		
UD-2	1	42.0 - 44.0	2	125.4	127.0	0.0	27.7
UD-2	1	42.0 - 44.0	3	124.0	126.5		
UD-2	2	108 - 109.5	1	129.8	134.9		
UD-2	2	108 - 109.5	2	133.5	135.9	0.0	34.6
UD-2	2	108 - 109.5	3	128.6	134.0		
UD-4	3	58.0 - 59.5	1	122.3	124.4		
UD-4	3	58.0 - 59.5	2	121.6	123.9	0.0	25.7
UD-5	1	42.0 - 44.1	1	131.5	132.5		
UD-5	1	42.0 - 44.1	2	129.5	131.4	0.0	38.9
			Average	126.7	129.5	0.0	31.7

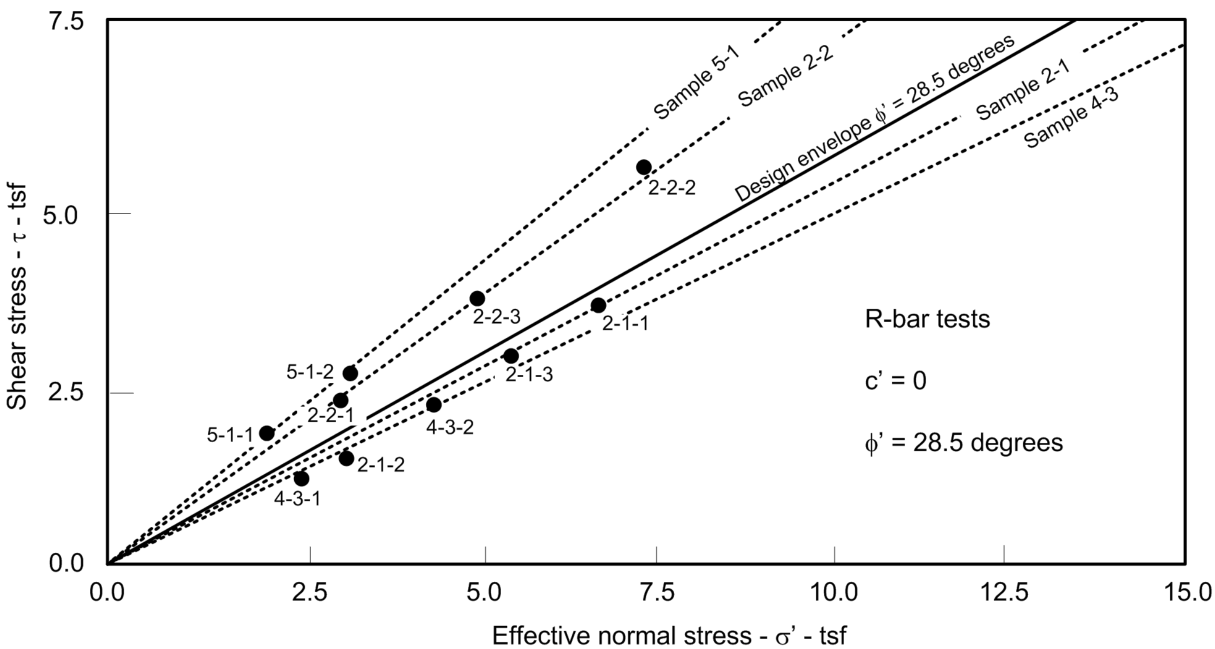


Figure 4-11. Presentation of design strength values

Critical circles			
Tangent elevation	X	Y	Factor of safety
815 ft.	182	1086	2.18 before drawdown 1.87 after drawdown
790 ft.	244	1074	2.15 before drawdown 1.64 after drawdown
775 ft.	280	1110	2.53 before drawdown 2.16 after drawdown

Soil Properties							
Mat'l	γ_{moist} pcf	γ_{sat} pcf	c' psi	ϕ' degs	$d_{K_c=1}$ psf	$\psi_{K_c=1}$ degs	Description
1	127	130	800	21	1700	13	Impervious core
2	132	136	400	18	1600	12	Random impervious
3	140	143	0	36	-	-	Pervious shell
4	114	127	0	28	-	-	Weathered rockfill
5	100	125	0	35	-	-	Proposed rockfill
6	135	140	0	33	-	-	Foundation outwash
7	-	130	0	27	-	-	Silty aluvium

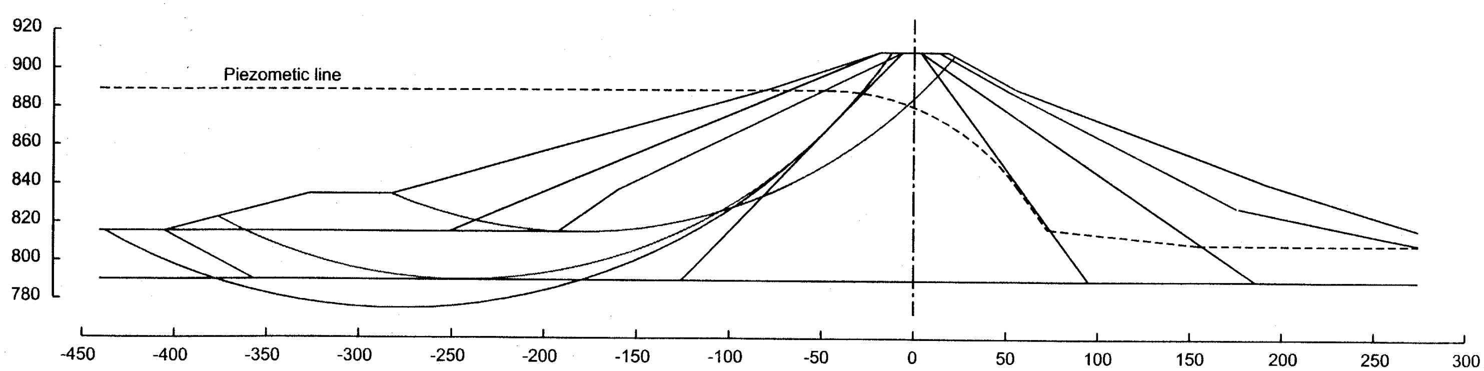


Figure 4-12. Presentation of slope stability analysis results